

Visions of the Future: Hybrid Electric Aircraft Propulsion



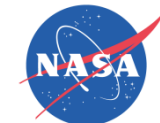
Cheryl Bowman

AIAA Aircraft Electric/Hybrid-Electric Power & Propulsion Workshop, July 28, 2016



Outline

- NASA's Motivation for Electrified Aircraft Propulsion Investment
- Strategic Thrust 4: Transition to Low Carbon Propulsion
- Hybrid and Electric Aircraft Propulsion Terminology
- NASA's Approach to Electrified Aircraft Propulsion
- Convergent Aeronautics Solutions: for High Risk and High Payoff
- SCEPTOR/X-57: Near Term Flight Demonstration
- Advanced Air Transport Technology: Long Term Aircraft Investment for Electrified Propulsion
- Summary



Electrified Aircraft Propulsion: Motivation

NASA Aeronautics Research Mission Directorate

Mega Drivers



Sustainable

Strategic Thrusts

6 Strategic Thrusts



Safe, Efficient Growth in Global Operations

Enable full NextGen and develop technologies to substantially reduce aircraft safety risks



Innovation in Commercial Supersonic Aircraft

Achieve a low-boom standard



Ultra-Efficient Commercial Vehicles

Pioneer technologies for big leaps in efficiency and environmental performance



Transition to Low-Carbon Propulsion

Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology



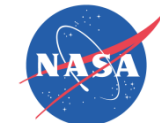
Real-Time System-Wide Safety Assurance

Develop an integrated prototype of a real-time safety monitoring and assurance system



Assured Autonomy for Aviation Transformation

Develop high impact aviation autonomy applications



Electrified Aircraft Propulsion: Motivation

Strategic Thrusts Guide Investment Targets

2015

2025

2035

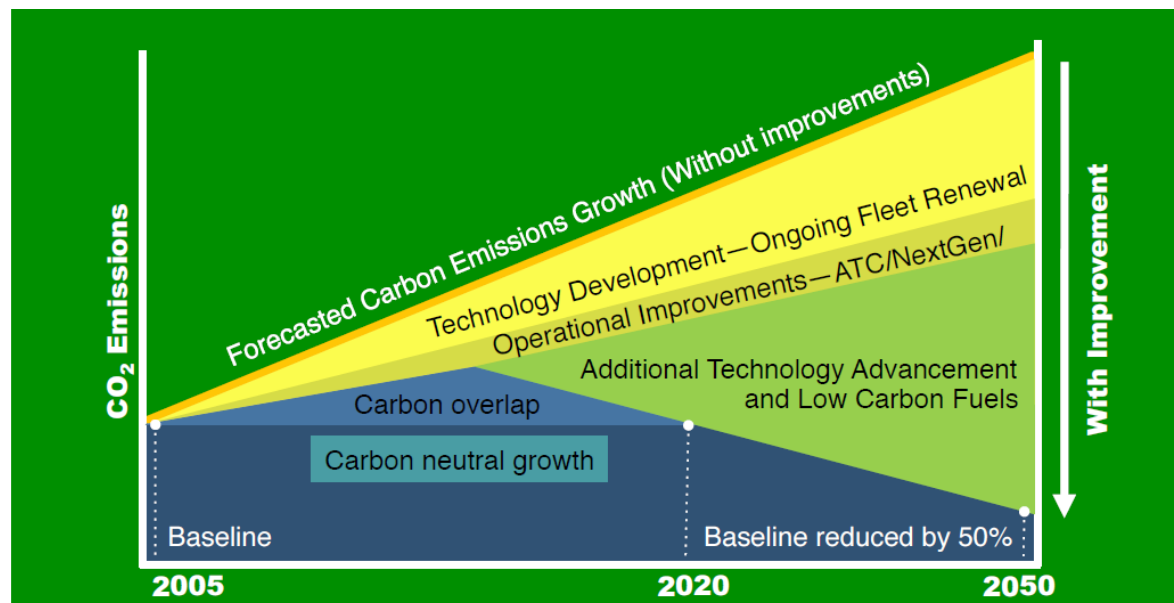


Introduction of Low-Carbon
Fuels for Conventional
Engines and Exploration of
Alternative Propulsion
Systems

Initial Introduction of
Alternative Propulsion
Systems

Introduction of Alternative
Propulsion Systems to
Aircraft of All Sizes

The Low Carbon Challenge is to enable carbon-neutral growth in aircraft operations:





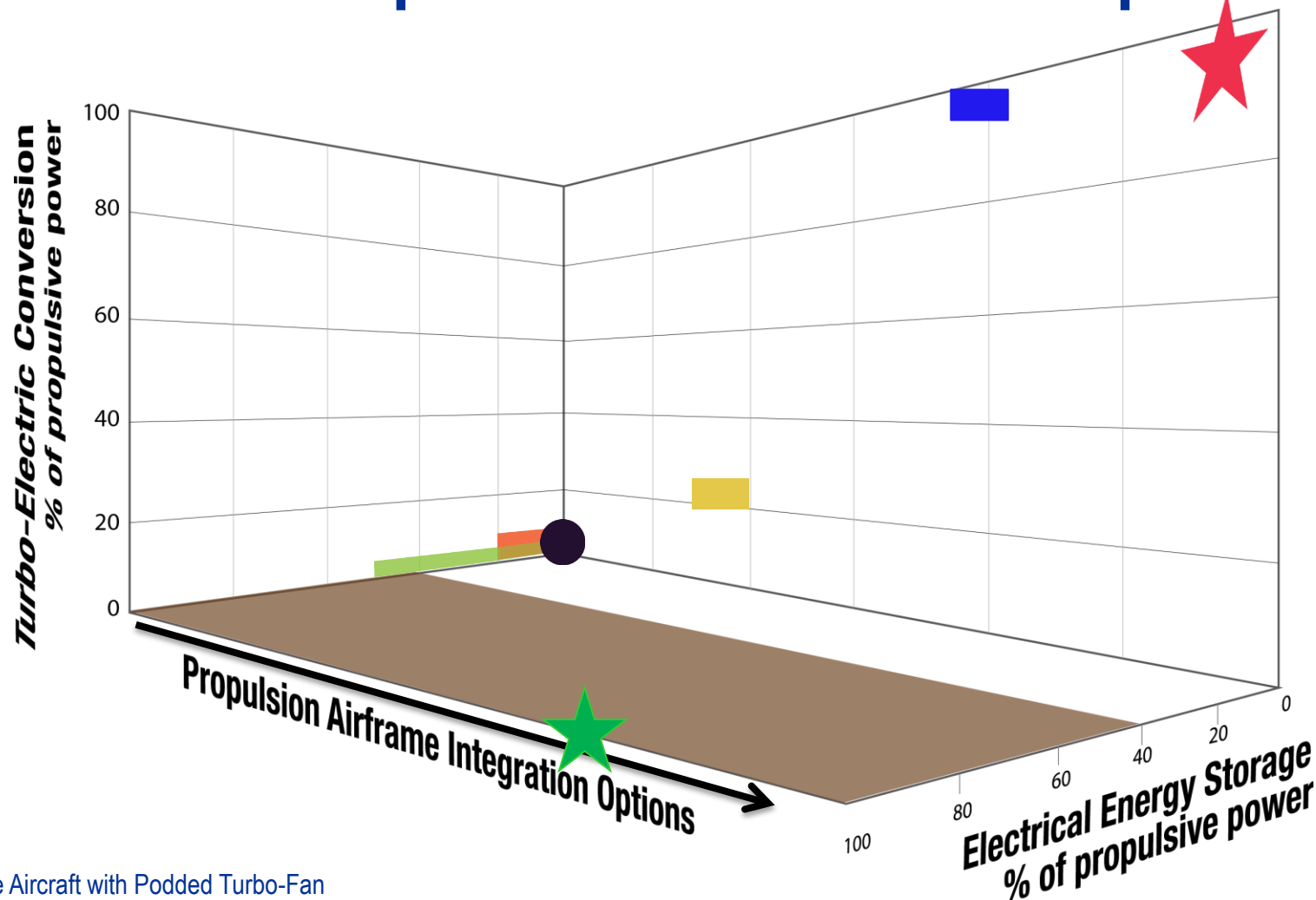
Electrified Aircraft Propulsion Terminology

- **Electrified Propulsion refers to the use of electric power for aircraft propulsion**
 - Could be all or partially electric propulsion
 - Other aircraft development programs use the terms “More electric” or “All electric” as the use of electric power for secondary systems on aircraft such as control surfaces and wing de-icing
- **Hybrid Electric has two meanings in aircraft context**
 - One meaning is the use of two power sources, such as turbine engine and electric motor, to drive the fan (or propeller) on an aircraft—hybrid electric powertrain
 - Another meaning is the combination of more than one propulsive sources such as engines, turboelectric energy generation, fuel cells energy generation, or battery energy storage—hybrid electric propulsion
- **Turboelectric Propulsion refers to on-air generated electric power for aircraft propulsion**
 - Turboelectric generation already provides electric power for secondary systems on aircraft
 - Fully turboelectric propulsion means that all turbine power goes to electricity
 - Partially turboelectric propulsion means a turbofan engine with some fraction of generated electric power going to propulsion





Electrified Propulsion Vehicle Trade Space



● Baseline Aircraft with Podded Turbo-Fan

VEHICLE CONFIGURATION EXAMPLES

★ SCEPTOR 4 PAX X-Plane

■ AATT 50 PAX STUDIES

■ SUGAR VOLT 150 PAX Study

■ Current NRA 150 PAX Studies

■ STARC-ABL 150 PAX Study

■ ECO-150 150 PAX Studies

★ N3-X 300 PAX Turbo-Electric

Electrified Propulsion: NASA's Approach

Build, Test, Mature Enabling Technologies and Knowledge Bases





Electrified Propulsion Development

Goal: Enable the paradigm shift to electric, hybrid electric, and turboelectric propulsion for reductions in energy consumption, emissions, and noise

Path:

- **Identify promising propulsion / vehicle configurations**
- **Buy-down risk for crucial technologies in**
 - **Flight Control: new knobs in vehicle and subsystems**
 - **Power Conversion: electric machines & electronics**
 - **Power Control: vehicle electric grid management**
 - **Fundamental Enablers: materials and analysis**
- **Demonstrate results in purpose-built flight demonstration**

Multiple Paths to Carbon Reduction

All Electric, Hybrid Electric, Distributed Propulsion

- On Demand Mobility Focus
- Small Plane Focused

Enable New Aero
Efficiencies

Power Sharing

Distributed Thrust
Control

Certification
Trailblazing

**Energy & Cost Efficient,
Short Range Aviation**

Turbo Electric, Distributed Propulsion

- Low Carbon Propulsion
- Transport Class Focused

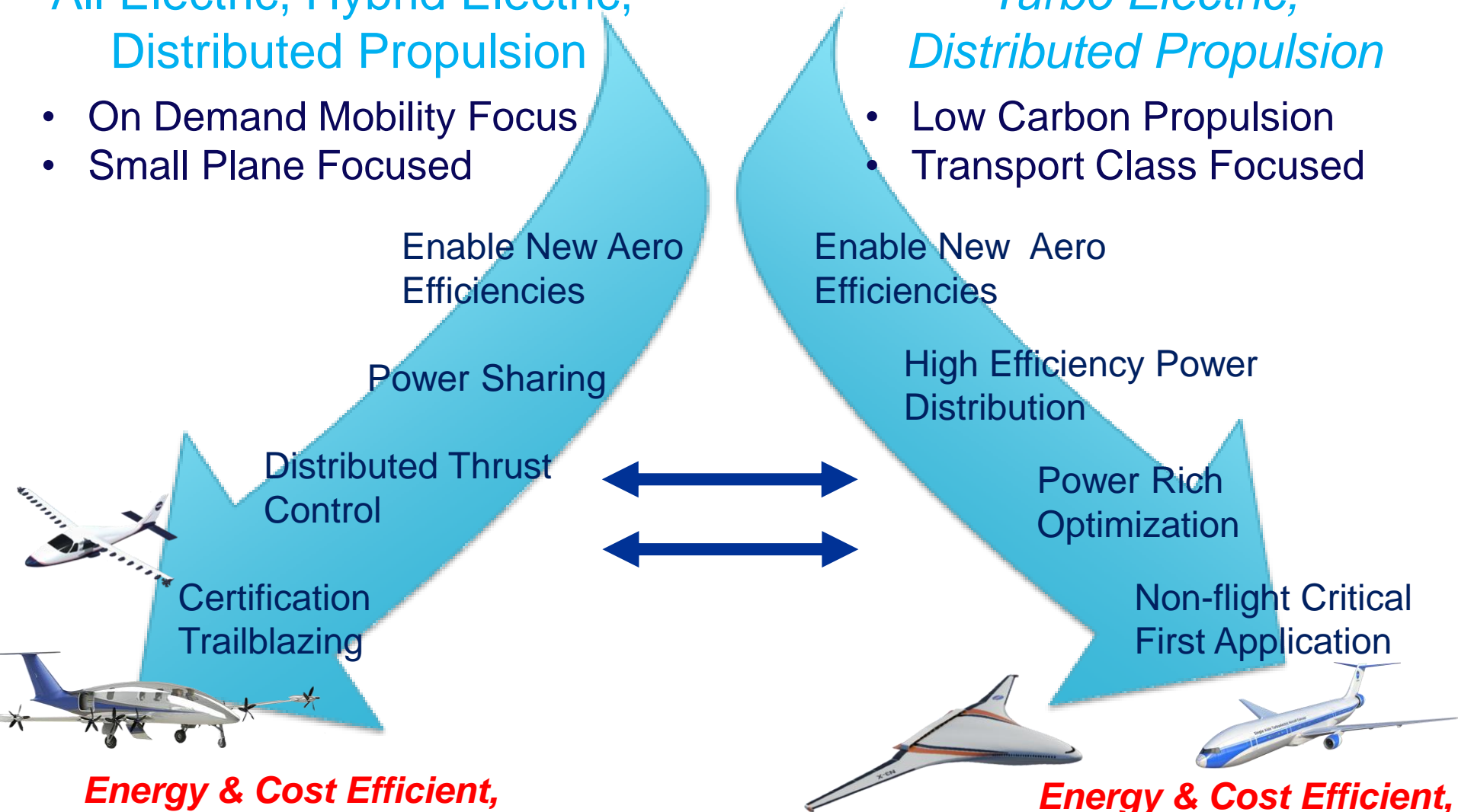
Enable New Aero
Efficiencies

High Efficiency Power
Distribution

Power Rich
Optimization

Non-flight Critical
First Application

**Energy & Cost Efficient,
Transport Aviation**





Convergent Aeronautics Solutions Project

Aircraft Hybrid/Electric Propulsion Activities

- **M-SHELLS – Multifunctional Structures for High Energy Lightweight Load-bearing Storage**
 - Integrates hybrid battery/supercaps into aircraft structure to increase effective specific power & specific energy
 - Converges advanced electrochemistries, microstructures, manufacturing, and nano-technologies
- **LION – Integrated Computational-Experimental Development of Li-Air Batteries for Electric Aircraft**
 - Investigates “electrolyte engineering” concepts to enables Li-Air batteries with high practical energy densities, rechargeability and safety
 - Converges advances in predictive computation, material science, and fundamental chemistry
- **HVHEP – High Voltage Hybrid Electric Propulsion**
 - Variable-frequency AC, kV, power distribution with DFIM machines for multi-MWe DEP applications
 - Minimizes constituent weights of power electronics, TMS, and fault protection
- **Compact High Power Density Machine Enabled by Additive Manufacturing**
 - 2 to 3x increase in specific power of electric machines for DEP enabled by additive manufacturing
 - Compact, lightweight motor designs/topologies, integrated cooling, and multi-material systems/components.
- **DELIVER – Design Environment for Novel Vertical Lift Vehicles – cryo-cooling HEP task**
 - Maximizing efficiency and power density of electronic components by cryogenic LNG-fuel cooling
 - Longer-range hybrid/electric UAS with reduced fuel-burn and emissions (CO₂, sulfur, particulates)
- **FUELEAP – Fostering Ultra-Efficient, Low-Emitting Aviation Power**
 - GA aircraft / early-adopter application of JP-fueled SOFC power plant for clean, hybrid/electric architecture
 - Zero NO_x electric power production at ~2x typical combustion efficiencies
- **SCEPTOR – Scalable Convergent Electric Propulsion Technology and Operations Research**
 - Seeks 5x reduction in cruise-energy-use by aerodynamic benefits of DEP & batteries in place of engines
 - DEP enables high efficiency wing & high performance wingtip motors for cruise



SCEPTOR X-57 Research Objectives

NASA SCEPTOR Primary Objective

- Goal: 5x Lower Energy Use (Comparative to Retrofit GA Baseline @ 150 knots)
- Motor/controller/battery conversion efficiency from 28% to 92% (3.3x)
- Integration benefits of ~1.5x (2.0x likely achievable with non-retrofit)



NASA SCEPTOR Derivative Objectives

- ~30% Lower Total Operating Cost (Comparative to Retrofit GA Baseline)
- Zero In-flight Carbon Emissions

NASA SCEPTOR Secondary Objectives

- 15 dB Lower community noise (with even lower true community annoyance).
- Flight control redundancy, robustness, reliability, with improved ride quality.
- Certification basis for DEP technologies.



Adv. Air Transport Technology Project Investment

**Integrated Vehicles and
Concepts Evaluation**

**Efficient, Low
Noise Propulsors**

**Boundary-Layer
Ingestion Systems**

**Highly Efficient
Turbine Engines**

**Power Systems
Architectures**

**Advanced Electrical
Components**





Adv. Air Transport Technology Project Investment

Objective

Key performance parameters and threshold level requirements for gas turbine aircraft augmented with electrical powertrain

Propulsion System Conceptual Design

- Concepts for system interaction exploration

Integrated Subsystems

- Flight control methodology for distributed propulsion

High Efficiency/Power Density Electric Machines

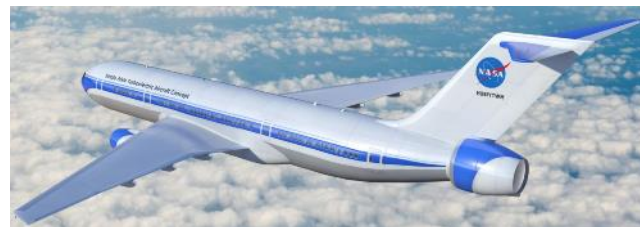
- Step change in component performance

Flight-weight Power System and Electronics

- High voltage power electronics, transmission, protection, and management

Enabling Materials

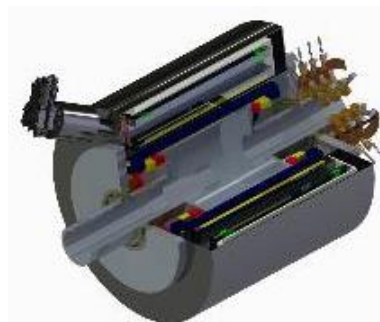
- Insulation, Conductors, Magnetic Materials



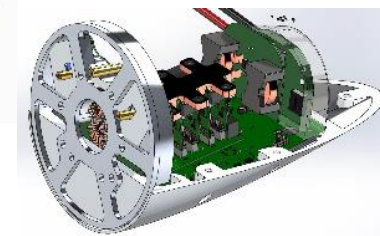
Scrutinizing tube & wing architectures



Revolutionary system testing



Superconducting
and ambient
machines



Transitioning materials
from lab to component



NASA Electrified Propulsion Takeaways

- NASA Aeronautics Strategic Thrust 4 -Transition to Low-Carbon Propulsion is supporting investment in alternative aircraft propulsion including electrified aircraft propulsion
- The NASA vision includes transforming aviation via new propulsion technologies integrated with airframes to
 - increase aircraft functionality
 - reduce carbon emissions
 - improve operational efficiency and reduce noise
- There are many possible Electrified Aircraft configurations
- NASA investment includes vehicle concepts and technology to support aircraft for
 - Small to midsize aircraft to increase mobility provide a new paradigm
 - Commercial transport aircraft to impact the current large carbon producing market segment

Timeline of Machine Power Relevant to Aircraft Class

